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STUDY OF FOOD PREFERENCE AND RATE OF FEEDING OF JAPANESE OYSTER DRILL Ocinebra japonica DUNKER

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STUDY OF FOOD PREFERENCE AND RATE OF FEEDING OF JAPANESE OYSTER DRILL, *Ocinebra japonica* (Dunker)

by

Kenneth K. Chew

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STUDY OF FOOD PREFERENCE AND RATE OF FEEDING OF JAPANESE OYSTER DRILL, Ocinebra japonica (Dunker)[1]

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ABSTRACT

Two experiments, of 70 days each, were conducted to determine food preference of the Japanese oyster drill, *Ocinebra (= Tritonalia) japonica*. Individually marked drills were presented with a choice of four different food organisms: bay mussels, *Mytilus edulis*; Manila clams, *Venerupis japonica*; Olympia oysters, *Ostrea lurida*; Pacific oysters, *Crassostrea gigas*. Daily observations were made on the location of each drill and the food animal being attacked.

The Japanese drills, which were originally collected from Pacific oysters, preferred either Manila clams, Olympia oysters, or bay mussels to Pacific oysters. Most of the drills attacked the same species of food organism attacked previously, and did not move to another organism of a different species.

Ocinebra usually took 4 to 5 days to drill and to finish feeding on bay mussels; 5 to 6 days for Pacific oysters; 6 to 7 days for Olympia oysters; and 7 to 8 days for Manila clams. The duration of attack by drills appeared to be related to the thickness of the shells of the prey.

THE PROBLEM

The Japanese oyster drill, *Ocinebra (= Tritonalia) japonica* (Dunker), is considered by oyster growers of the Pacific coast to be potentially the most serious predator on Pacific *(Crassostrea gigas)* and Olympia oysters *(Ostrea lurida)*. *Ocinebra* was introduced to the Pacific coast of America with the importation of Japanese seed oysters (Galtsoff, 1929). This drill has become well established in several bays of Puget Sound in the State of Washington (Galtsoff, 1932). It has also been found to occur in the water along the Canadian Pacific coast (Elsey, 1935), as well as in California and Oregon oyster growing areas.

Although *Ocinebra japonica* has been found to drill oysters with resultant

[1]Contribution No. 44, College of Fisheries, University of Washington, Seattle, Washington.

Note.--Kenneth K. Chew, Fisheries Research Assistant, College of Fisheries, University of Washington, Seattle, Washington.

damage to oyster stocks (Cahn, 1950; McKernan, Tartar, and Tollefson, 1949), little has been done to establish the drill's order of preference for the organisms it is known to attack. Chapman and Banner (1949) reported that *Ocinebra* attacks Olympia oysters in preference to bay mussels *(Mytilus edulis)* and barnacles. A preliminary study of Chew and Eisler (1958) indicated that the Japanese drill preferred bay mussels and Manila clams *(Venerupis japonica)* to Pacific or Olympia oysters. In addition, this study suggested that these drills might develop a preference for a particular species of food.

The present study was made between July 4 and November 21, 1957, in the salt-water aquarium of the College of Fisheries, University of Washington. The purpose of the experiment was two-fold:

1. To ascertain if *Ocinebra japonica* exhibited discrimination in its choice of food when given an equal opportunity of attacking any of four species of bivalves (bay mussel, Manila clam, Olympia oyster, and Pacific oyster).

2. To determine if a relationship existed between the thickness of shell of the food organism and the time required for *Ocinebra japonica* to perforate the shell and finish feeding.

EQUIPMENT AND MATERIALS

Aquaria

Four cement aquaria were used in this study. Inside dimensions of each aquarium measured 61 cm. wide, 140 cm. long, and 66 cm. high. The smooth bottoms and sides of the four aquaria were painted dull black. The two longer sides of each aquarium were of plate glass, covered with dark paper to prevent light from entering through the sides.

Water

Water level in the four aquaria was maintained at 30 cm. Sea water from Puget Sound was recirculated through the aquaria at the rate of 1 liter per 20 seconds. Inflow and outflow of water were at opposite ends of the aquaria, approximately 132 cm. apart.

Water was directed into each aquarium striking against the wall. A piece of wood lath was placed across the inflow side of the aquarium to prevent foam from floating across the surface. Water then flowed out through a tilted drain pipe.

Throughout the study, water temperature was maintained at 11.9° C. (±0.30° C.) by refrigeration units of the salt-water system. It is unknown whether this was or was not the optimum temperature for active drilling and feeding of *Ocinebra japonica*, since virtually nothing is known about the feeding of this species of drill in relation to temperature. It is generally understood that the water temperature is an important factor governing the feeding rate of *Urosalpinx cinerea* (Carriker, 1955; Cole, 1942; Hancock, 1959). In the United States, the temperature at which *Urosalpinx* commences drilling varies in different localities (Carriker, 1955), from 6.5° C. in Virginia (Carriker, 1955, cited by Hancock, 1959) and 7.5° C. in Long Island Sound (Hanks, 1957) to 15.0° C. in North Carolina and Virginia (Federighi, 1931). Cole (1942) found that *Urosalpinx* in England commenced drilling as soon as the water temperature exceeded 11.0-12.0° C. Hancock (1959) found that *Urosalpinx* kept in the Fisheries Laboratory at Burnham-on-Crouch, Essex, in 1953 continued feeding until the average water temperature dropped to 9.0-10.0° C.

When test animals were collected in the field water samples were taken to measure changes in hydrogen-ion concentration (pH) and salinities to which the drills were subjected in being transferred from the field to the aquarium. Results of the sampling are as follows:

Exp. I, 6/27/57 in field, pH 7.85 and salinity 28.12 ‰
6/28/57 in aquarium, pH 7.15 and salinity 29.40 ‰

Exp. II, 9/5/57 in field, pH 7.47 and salinity 28.97 ‰
9/6/57 in aquarium, pH 7.59 and salinity 29.53 ‰

Light

A 100-watt incandescent lamp over each test aquarium was mechanically turned on every morning and off every evening. By varying the voltage gradually, it required 35 minutes for the lamps to reach maximum illumination in the morning (5:05 a.m. to 5:40 a.m.) and 34 minutes to decrease the illumination until completely extinguished in the evening (8:30 p.m. to 9:04 p.m.). This was done to approximate sunrise and sunset conditions.

Shell Thickness

Thickness of shells perforated by Japanese drills was measured to the nearest 0.0001 inch with a full-jeweled, dial indicator, as shown in figure 1.

Test Animals

All test animals were collected from oyster beds of the Olympia Oyster Company, Oyster Bay (Southern Puget Sound), Washington. To obtain a group of test animals that were from approximately the same environmental surroundings, all subjects for this study were collected at a single locality within a radius of about 150 yards. To insure uniformity, all drills were collected from the surface of Pacific oysters. All test animals for Experiment I were collected on June 27, 1957, and for Experiment II on September 5, 1957.

Since it was not possible to ascertain the sex of drills by external characteristics, it was assumed that the sex ratio was equal. Attempts to determine the sex of *Ocinebra* with the Hargis (1957) rapid live-sexing technique failed.

Of the four food species, bay mussels were taken from oyster dyke walls; Manila clams were dug from the gravel parts of oyster beds; and Olympia and Pacific oysters were picked from the beds.

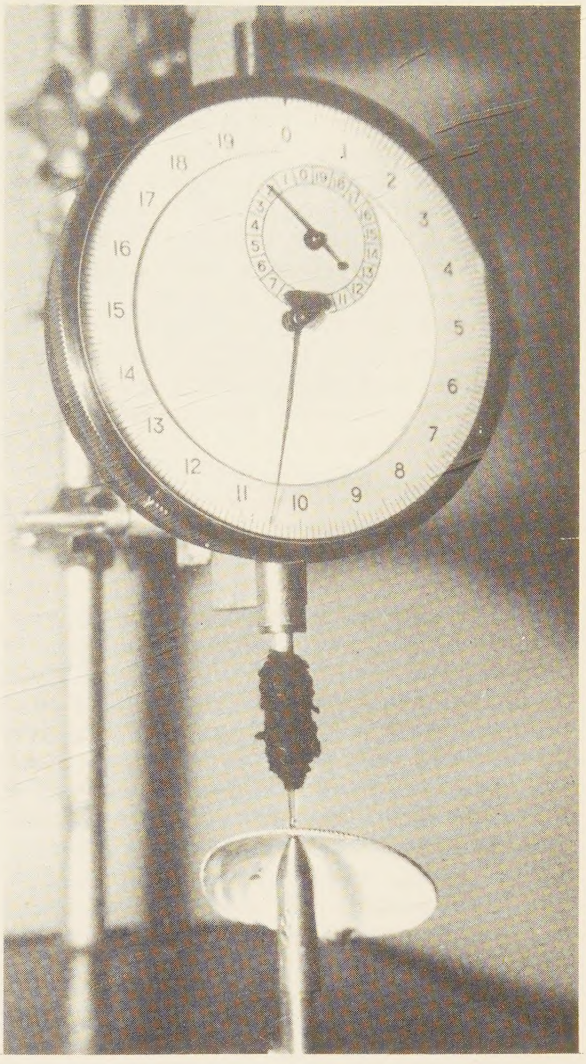

Figure 1.--The thickness of a Manila clam shell indicated by dial meter.

METHODS

Conditioning and Measuring

Prior to the test, drills collected for Experiment I were conditioned to the salt water of the aquarium for 7 days, during which time they were not fed. On the first day of the acclimatizing period, the drills were all measured as shown in figure 2. The apex of the whorl was placed against a backstop, and reading in millimeters was taken at the tip of the anterior siphonal canal. Drills which fell within an arbitrarily selected size range around

Figure 2.--Measuring the length of a Japanese drill.

the mean were used to represent the adult drill population.

On the second day of the conditioning period, drills needed for Experiment I were selected at random from the specified size group and painted for identification with synthetic paint (Speedtec Synthetic Finish). One color was painted on the apex and another color on the varices. Various color combinations were made with silver, yellow, red, and blue paints. Drills for Experiment II were collected, measured, and conditioned in an identical manner.

The bay mussels, Manila clams, Olympia oysters, and Pacific oysters were measured in the plane of greatest shell length. For each food species an arbitrary size range around the mean was selected to represent the most available adult food population for the drills.

Size Grouping

Table 1 represents the number collected, mean lengths, "t" values, and size ranges of animals used for Experiments I and II. For each species of test animal, a statistical "t" test was conducted to determine if the mean lengths of animals collected for Experiments I and II were significantly different. If a "t" value, evaluated at the 5 percent level, revealed no significant difference between mean lengths, the same size ranges used in Experiment I were used for Experiment II. However, if a significant difference was found between the mean lengths of Experiment I and Experiment II animals, the group for Experiment II was selected around the second mean rather than the mean of Experiment I. The number of animals used in the second experiment was nearly the same percentage of those collected as in the first experiment.

Table 1.--Numbers, mean lengths, "t" values, and size ranges of test animals

Test animals	Experiment I			Experiment II			"t" values 2/
	No.	Mean length mm.	Size range mm. 1/	No.	Mean length mm.	Size range mm. 1/	
Japanese drills	210	32.4	29-37 (67.6% of sample)	187	34.6	31-38 (66.3% of sample)	-4.33 (sign.)
Bay mussels (M)	361	45.1	40-50 (77.3% of sample)	332	44.3	39-50 (76.5% of sample)	-2.35 (sign.)
Manila clams (C)	520	45.6	40-50	418	46.2	40-50	-1.38 (not-sign.)
Olympia oysters (O)	379	34.0	29-39	294	34.3	29-39	-0.79 (not-sign.)
Pacific oysters (P)	250	55.9	50-60 (59.6% of sample)	195	62.8	58-69 (58.0% of sample)	-10.80 (sign.)

1/ Percentages of samples are given only when the "t" values are significant.

2/ (sign.) = significant difference between the mean lengths of the two samples at the 5% level, and (not-sign.) = no significant difference.

As shown in table 1, the size range of Manila clams (40 to 50 mm.) used for Experiments I and II was the same. The size range used for Experiments I and II was also the same for Olympia oysters (29 to 39 mm.). The reason for using the same size range was that for each of these two species a statistical "t" test showed that the mean length of the first sample for Experiment I was not significantly different from the mean length of the second sample for Experiment II.

Because there were significant differences in the mean lengths of samples collected for Experiments I and II, size ranges were changed for Japanese drills (from 29-37 mm. to 31-38 mm.), bay mussels (from 40-50 to 39-50), and Pacific oysters (from 50-60 to 58-69).

Even though the bay mussels were collected from the same area, their mean lengths for the sample used in Experiment II showed a significant decrease of .87 mm. from the sample used in Experiment I. Other species of bivalves increased in mean length between the samples taken for Experiments I and II, as might be expected. The mean length of the bay mussels decreased probably because more of the year class "0" were included in the second collection.

Design of Experiment

Two experiments, designated Experiment I and Experiment II, were conducted over a period of 70 days following the procedure shown in figure 3. In Experiment I, July 4 to September 12, 1957, the four replicates were designated tanks 1, 2, 3, and 4. In Experiment II, September 13 to November 21, 1957, tank 2 was a continuation of Experiment I. Whereas newly collected drills and food were placed in tanks 1, 3, and 4.

At the beginning of each experiment, 18 randomly selected drills were marked and arranged in a systematic pattern in each tank as shown in figure 4. For identification and consistency, the color combination for each drill location was the same for all tanks. For example, all D1 drills were red/red (apex/varices), and all D2 drills were red/silver.

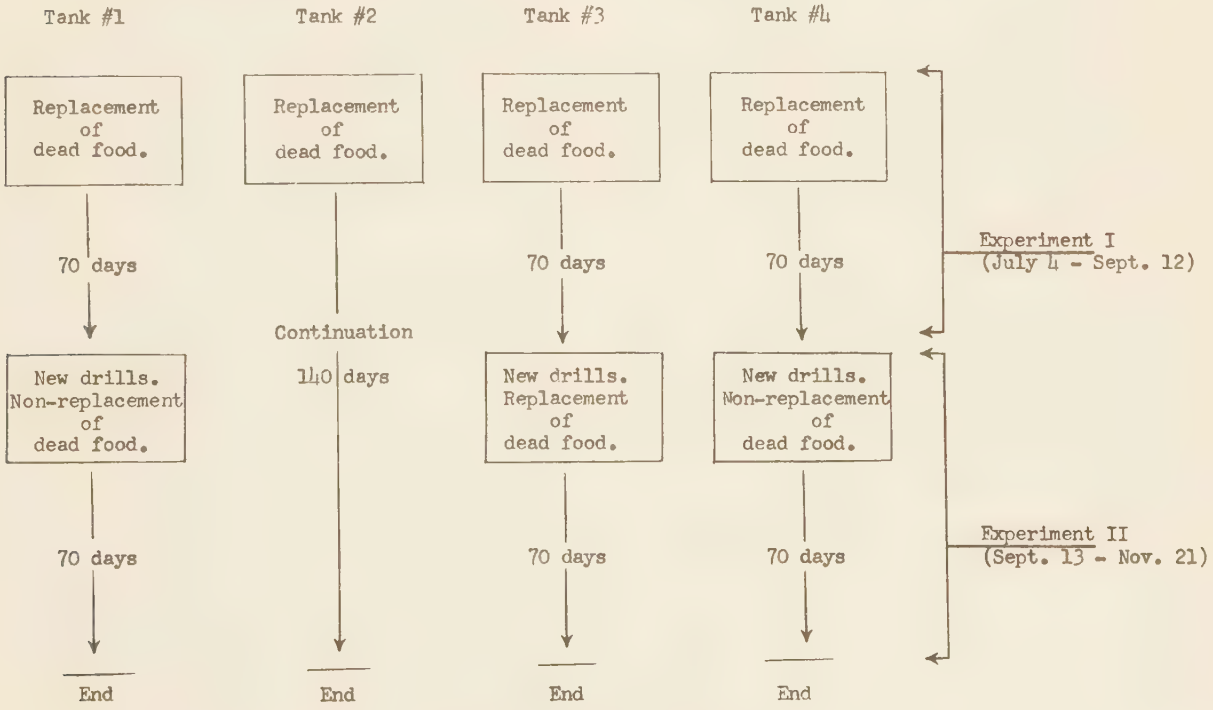

Figure 3.--Design of experiment.

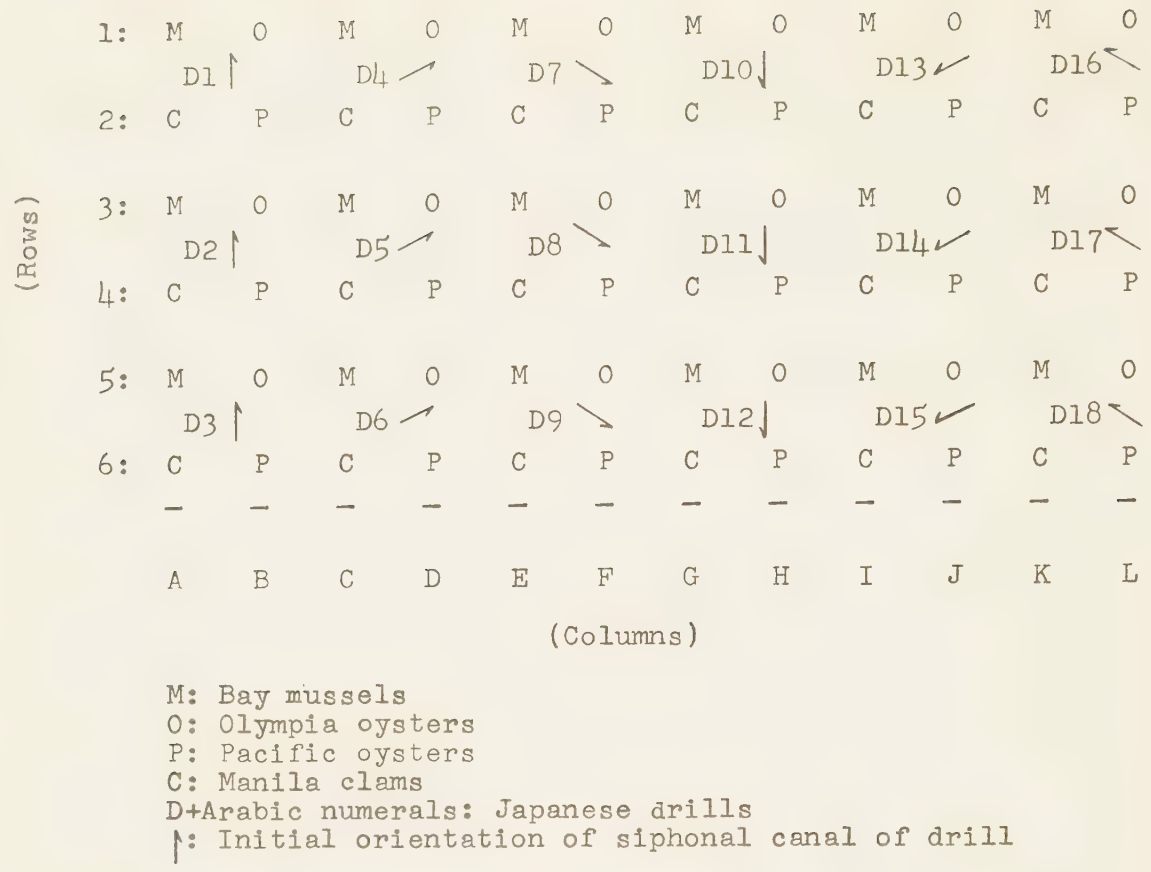
1: M O M O M O M O M O M O
D1 D4 D7 D10 D13 D16
2: C P C P C P C P C P C P
3: M O M O M O M O M O M O
D2 D5 D8 D11 D14 D17
4: C P C P C P C P C P C P
5: M O M O M O M O M O M O
D3 D6 D9 D12 D15 D18
6: C P C P C P C P C P C P
A B C D E F G H I J K L
(Rows)
(Columns)
M: Bay mussels
O: Olympia oysters
P: Pacific oysters
C: Manila clams
D+Arabic numerals: Japanese drills
Initial orientation of siphonal canal of drill

Figure 4.--Arrangement of food organisms and position of each drill at time of release for Tank 1.

The siphonal canals of all drills in each column were pointed a certain direction at release as shown in figure 4. The direction of drills in each column differed by 60 degrees from those in adjacent columns. This was done in each tank to check the initial movement of the drills toward the four species of food offered (directioned variable). Eighteen food animals of each species were used in each tank. The only difference between the four tanks in Experiment I was the position of the food animals. Each species of food animal was shifted clockwise one place from tanks 1 through 4. For example, the following squares represent the position of food animals in each tank of Experiment I:

Tank 1.	Tank 2.	Tank 3.	Tank 4.
M O	C M	P C	O P
C P	P O	O M	M C

The individual food animals were placed at equal distances from each other (4.5 inches) with the aid of small yellow dots of synthetic paint, painted on the bottom of the four test aquaria before the experiment.

In figure 3, "replacement of dead food" means that when a food animal was drilled and eaten, it was taken out and replaced by another animal of the same species. The food animal was not removed and replaced until the drill had finished its attack and moved away. The credit for this mortality, in number of days, was given to the drill first noted on the dead organism. The shell of the drilled and eaten food animal was then placed in an envelope and filed away for later use. At the end of Experiment I, all shells collected were measured for thickness.

"Non-replacement of dead food" indicates that after a food animal was drilled and eaten and the drill had moved away, the animal was taken out and cleaned of whatever meat was left. The shell was then replaced in its original location on the design.

After 70 days of Experiment I, tanks 1, 3, and 4 selected by random numbers were provided with test animals to begin Experiment II. The original test animals were kept in tank 2 throughout Experiment II to determine if any changes occurred in their feeding behavior over a longer test period.

The tests in tanks 1 and 4 of Experiment II in which dead food was not replaced were conducted to determine if drills would completely finish a preferred species before turning to another. This phase of the experiment was designated "non-replacement of food" test.

An *Ocinebra* usually stayed on one individual food animal for several days. As soon as the drill moved off or left a food organism, this animal was taken out of the aquarium and examined for drill holes. If there was a drill hole, the animal was considered dead. When it was found that a hole had been drilled through a valve of a mussel or clam, the soft parts of the visceral mass were gone, leaving intact the harder parts such as the siphon in the clams, mantle edges, foot, and parts of the adductor muscles. Usually, only fragments of the adductor muscles were left in oysters. These findings were in general agreement with those who worked with other species of drills [Carriker, 1954; McConnel, 1954; and Chapman, 1956].

Carriker (1955) points out that the radula of *Urosalpinx* is ineffective in rasping tissues such as the adductor muscles of adult oysters until partial autolysis has taken place. It is possible that the temperature of the water (11.9° C.) in the two experiments may have delayed normal autolytic action in the hard parts of the visceral mass of drilled bivalves. *Ocinebra* may have been discouraged by this delay and consequently left the hard parts of the visceral mass partially or wholly intact in the bivalves.

Effects of Current

A series of experiments by Federighi (1929) showed that *Urosalpinx cinerea* (Say) orients precisely and will move against a current of water (rheotropism). Therefore, prior to Experiments I and II of this study, tests were conducted on the possible effects of water currents on the drills' initial movements in each tank. Prior to Experiment I, a total of 72 unmarked drills within the specified size range were placed without food on the 18 positions marked in each of the four tanks (figure 4). The drills were observed every half hour for 4 hours. No definite pattern was observed, and movement of the drills was assumed to have been random. The same applies for the 54 unmarked drills tested in tanks 1, 3, and 4 before starting Experiment II.

RESULTS

A summary of the major observations is presented in tables 2 through 8. In these tables, column A represents the species of food animal attacked (C = clam, M = mussel, O = Olympia oyster, and P = Pacific oyster); column B represents the location; and column C represents the number of days the drill remained on the victim.

Attacks by Drills

"Replacement of food" test.--There was a difference between the relative numbers of different types of pelecypods attacked by drills in the four different tanks of Experiment I. This was confirmed by a chi-square value (χ^2) of 33.04, which was significant at the 5 percent level, with 9 degrees of freedom (table 9). When the results of tank 2 in Experiment I were excluded in the test, a χ^2 value of 5.18 was obtained (table 10). This indicates that the distribution of attacks between the different species of pelecypods of tanks 1, 3, and 4 of Experiment I were not significantly different.

Table 2.--Location, number and duration of attacks by the drills, and food organisms involved, for tank 1, Experiment I

A: species attacked [1/] B: location [2/] C: duration of attack in days

Drill number	1st attack	2nd attack	3rd attack	4th attack	5th attack	6th attack
	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C
1						
2	M-K1-5					
3	C-C4-5	C-I2-8				
4						
5	M-A3-5					
6	P-L6-7					
7	O-L5-9	O-L3-4	O-F1-9	O-H5-8		
8	C-K6-7	C-C4-5				
9	P-D6-6	O-L5-8	O-B5-7			
10	O-D3-10	C-L3-6	C-G2-6			
11	M-I1-4	M-A5-5	M-K3-5	M-C5-3	M-I5-4	M-I1-4
12	P-F4-2					
13	C-G4-4					
14	C-K6-9	C-G6-7				
15	O-H1-12	O-H5-4	C-E4-7			
16	C-E6-8					
17	C-G4-8	C-I4-8	C-E4-8	C-E2-4	C-A6-6	
18	P-L2-5	P-H6-2	C-G2-9	C-I4-11	C-K4-8	

1/ M = mussels; C = clams; O = Olympia oysters; P = Pacific oysters.

2/ Gives column and row where attack took place (see figure 4).

Table 3.--Location, number and duration of attacks by the drills, and food organisms involved, for tank 2, Experiments I and II

A: species attacked [1/] B: location [2/] C: duration of attack in days

(The underlined attacks occurred during Experiment II)

Drill number	1st attack A-B-C	2nd attack A-B-C	3rd attack A-B-C	4th attack A-B-C	5th attack A-B-C	6th attack A-B-C
1	O-F4-5	O-L2-7	C-K3-7			
2	O-J6-6					
3	C-C3-12	C-E3-7	C-G1-7	C-G5-8	C-K1-6	C-I5-6
4	O-L6-8	C-K1-7	C-K5-10	C-K3-11		
5	C-K1-8	C-K3-5	C-G5-7	C-K3-6	C-K5-7	
6	O-L6-12					
7	C-K3-7					
8	C-K5-7	C-G3-11	C-E1-8	C-C5-13	C-E5-11	C-I5-9
9	C-E1-10	C-C1-8				
10						
11	O-J4-6	O-J2-3	C-C3-12	C-C1-8	C-K3-7	C-C1-7
12	O-H2-3					
13	O-J2-2	O-L6-6	O-J4-8	O-J4-7	O-B6-6	
14	O-F6-12	O-D4-12	O-F2-7	O-F2-3	O-B6-4	
15						
16	O-H2-7	O-L2-4	O-F4-4	O-H2-8		
17	O-D4-3	C-I1-7	C-G1-9	C-K1-7	C-K1-7	
18	O-L4-10	C-I3-9	C-C3-11	C-K1-5	C-I5-3	

1/ M = mussels; C = clams; O = Olympia oysters; P = Pacific oysters.

2/ Gives column and row where attack took place (see figure 4).

Table 4.--Location, number and duration of attacks by the drills, and food organisms involved, for tank 3, Experiment I

A: species attacked [1/] B: location [2/] C: duration of attack in days

Drill number	1st attack	2nd attack	3rd attack	4th attack	5th attack	6th attack
	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C
1	P-G1-3	O-K6-10	O-E4-13			
2	P-A1-6	M-D4-4	M-L2-3			
3	O-A6-6	C-F5-8				
4						
5	C-L3-9	C-D1-4				
6	C-J5-11					
7	P-I1-6	M-L6-4	M-D2-6			
8	M-L6-6	M-J4-6	M-J6-4	M-L4-3	M-J6-4	M-L4-5
9	C-L5-2	C-J1-7				
10	C-H1-11	O-E6-3				
11	C-L1-9	C-L1-7	C-L3-8			
12	C-L1-7	C-L5-8	C-J3-11	O-C6-3		
13						
14						
15	O-C4-11	O-E2-5	C-F1-5			
16	C-J1-10	C-H3-5	C-B1-9			
17	P-C3-3	P-K5-3	P-G3-5	P-E5-7	M-B6-4	M-B6-4
18	O-I6-4	C-L1-5	C-L5-7			

1/ M = mussels; C = clams; O = Olympia oysters; P = Pacific oysters.

2/ Gives column and row where attack took place (see figure 4).

Table 5.--Location, number and duration of attacks by the drills, and food organisms involved, for tank 4, Experiment I

A: species attacked [1/] B: location [2/] C: duration of attack in days

Drill number	1st attack	2nd attack	3rd attack	4th attack	5th attack	6th attack	7th attack
	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C
1	P-J1-7	P-J1-7					
2	O-E3-9	C-F2-4					
3	O-A5-6	M-A6-3	M-C6-4	M-C4-3	M-A4-3	M-A6-3	
4	M-A2-4						
5	C-L6-8	C-L4-9					
6	O-E1-6	O-A3-4	O-A5-6				
7							
8	O-K1-7	O-C5-11	O-E1-7				
9	P-H5-7						
10	C-F2-8	C-D4-7	C-B2-3	C-B6-2			
11	C-J4-11	C-B4-5					
12							
13	M-I6-2	M-E2-3	M-A6-3	M-C6-3	M-I4-4	M-A4-3	M-G6-4
14	M-I2-8	M-I4-5	M-E2-5				
15	P-B1-3	O-K5-7					
16	P-L5-8						
17	O-I5-3	O-C3-4					
18	P-L3-7	C-B4-3	C-L4-5	C-J2-6			

1/ M = mussels; C = clams; O = Olympia oysters; P = Pacific oysters.

2/ Gives column and row where attack took place (see figure 4).

Table 6.--Location, number and duration of attacks by the drills, and food organisms involved for tank 1, Experiment II

A: species attacked [1/] B: location [2/] C: duration of attack in days

Drill number	1st attack	2nd attack	3rd attack	4th attack	5th attack	6th attack	7th attack	8th attack
	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C
1								
2	O-J3-5	C-G4-4						
3	O-D1-4							
4	C-C6-6	C-E6-6	C-E4-5	C-K2-8				
5	O-H3-3	O-H1-4	O-F5-7					
6	O-L5-9	O-B1-7						
7								
8	O-D3-8	O-F3-7	O-L3-4	M-I3-2	M-E1-3	M-I1-6	M-G1-5	M-G5-4
9	C-A6-9	C-I2-8	C-G6-4	M-K1-4	M-A5-4	M-E3-3		
10	O-D5-7	O-B5-7						
11								
12	O-J1-6	O-L1-5						
13	C-E2-3	M-I5-4	M-G3-3					
14	O-F1-6							
15	C-I6-11	C-K6-9	C-I4-6					
16	M-A1-4							
17								
18	M-C5-5							

1/ M = mussels; C = clams; O = Olympia oysters; P = Pacific oysters.

2/ Gives column and row where attack took place (see figure 4).

Table 7.--Location, number and duration of attacks by the drills, and food organisms involved, for tank 3, Experiment II

A: species attacked [1/] B: location [2/] C: duration of attack in days

Drill number	1st attack	2nd attack	3rd attack	4th attack	5th attack
	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C
1	O-G6-4	O-G4-6	O-K6-11	O-K2-7	
2	O-E6-5	O-E2-5			
3					
4	C-J1-7	C-F5-10	C-J5-4	C-L3-6	
5	C-B1-10	C-J1-11	C-J1-5		
6	O-E4-5	O-E6-8	O-E6-5	O-C6-8	
7	O-I2-8	O-G2-6	O-I2-4	O-C2-6	O-G2-10
8					
9	M-L2-4	M-F2-5	M-J5-5	M-J5-5	
10	O-K4-5	O-I6-5	O-I4-5	O-A2-5	
11	O-I6-6	O-K2-7	P-K1-6		
12	O-G2-5				
13	O-E6-6	O-G2-7	O-K2-7		
14	C-L1-10	C-F1-6			
15	O-I4-6	O-K6-7	O-G6-6		
16	C-L5-10	C-H1-10			
17	O-G4-6	O-I4-4			
18	O-A2-10	O-C2-3			

1/ M = mussels; C = clams; O = Olympia oysters; P = Pacific oysters.

2/ Gives column and row where attack took place (see figure 4).

Table 8.--Location, number and duration of attacks by the drills, and food organisms involved, for tank 4, Experiment II

A: species attacked [1/] B: location [2/] C: duration of attack in days

Drill number	1st attack	2nd attack	3rd attack	4th attack	5th attack
	A-B-C	A-B-C	A-B-C	A-B-C	A-B-C
1					
2	C-L4-9				
3	O-C1-7				
4	C-D2-9				
5	O-I3-8	O-G1-5			
6	C-F6-4	C-D4-9	C-B2-9		
7	M-A6-5	M-E2-6	M-G2-4	M-E4-4	
8	M-A4-6	M-C4-7	M-C6-5		
9	C-F2-10	C-B6-8	C-L6-6	C-J6-8	M-I4-3
10	O-A5-9	O-C5-7	O-E3-4	M-C2-7	M-G6-3
11	M-I2-5	M-K4-5	M-K6-7		
12	O-I1-5	O-K5-5	M-I6-6		
13	P-H1-5				
14	O-A1-8				
15	O-E5-6	M-A2-7	M-K2-7	M-G4-5	
16	O-G5-5	O-K3-4	O-I5-4		
17	O-A3-6	O-C3-7	C-B4-13	C-D6-7	C-J4-5
18	O-K1-7	O-G3-7	O-E1-5	C-L2-9	C-J2-8

1/ M = mussels; C = clams; O = Olympia oysters; P = Pacific oysters.

2/ Gives column and row where attack took place (see figure 4).

There was no difference between the relative numbers of different types of pelecypods attacked by drills in tank 2 of Experiment I and check Tank 3 of Experiment II. A X^2 test on the data supports these results (table 11).

Differences occurred between the distribution of first attacks on the different species of bivalves made by drills in each of the four tanks of Experiment I. This was confirmed by a X^2 value of 18.41 which was greater than 16.92 at the 5 percent level of significance, with 9 degrees of freedom (table 12). When the results of tank 2 of Experiment I were excluded, a X^2 value of 3.64 was obtained (table 13). This value indicates that the distribution of first attacks among the different species of tanks 1, 3, and 4 of Experiment I were not significantly different.

No difference was found between the distribution of first attacks on the different species of bivalves of tank 2, Experiment I, and check tank 3, Experiment II. This was confirmed by a X^2 test on the data (table 14).

Tank 2 "continuation test".--Of 16 drills that attacked food animals, 12 made more than one attack during the "continuation test" (table 3). Eleven of the 12 drills attacked during the second time period. Of these 11 drills, three changed their choice of food from Olympia oysters to Manila clams, and the other eight continued to attack the species they attacked last during Experiment I.

"Non-replacement of food" tests.--There was no difference between the relative numbers of different types of bivalves attacked by drills in tanks 1 and 4 of Experiment II (tables 6 and 8), as confirmed by X^2 test (table 15). Also, no significant difference was found between the distribution of the first drill attacks of the two tanks (table 16).

The results of tanks 1 and 4 of Experiment II were combined (table 17) to show which species of food was preferred. Eighteen individuals of each species of food were available to the 18 drills in each tank. As shown in table 17, 33 Olympia oysters were attacked during the first, second, and third attacks by the drills. The bay mussels and Manila clams were not attacked as readily as the Olympia oysters, and Pacific oysters were least favored.

Table 9.--Chi-square test of the relative numbers of different types of organisms attacked in the four tanks of Experiment I

(T = Tank)

Types of food	Observed				Expected				Total
	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4	
Bay mussel	8	0	12	16	8.95	7.20	10.04	9.82	36
Manila clam	19	13	19	12	15.65	12.60	17.56	17.18	63
Olympia oyster	9	20	8	11	11.93	9.60	13.38	13.09	48
Pacific oyster	5	0	7	6	4.47	3.60	5.02	4.91	18
Total	41	33	46	45	41.00	33.00	46.00	45.00	165

Chi-square value of 33.04, with 9 degrees of freedom.
(Significantly different)

Table 10.--Chi-square test of the relative numbers of different types of organisms attacked in tanks 1, 3, and 4 of Experiment I.

(T = Tank)

Types of food	Observed			Expected			Total
	T_1	T_3	T_4	T_1	T_3	T_4	
Bay mussel	8	12	16	11.18	12.55	12.27	36
Manila clam	19	19	12	15.53	17.42	17.05	50
Olympia oyster	9	8	11	8.70	9.76	9.54	28
Pacific oyster	5	7	6	5.59	6.27	6.14	18
Total	41	46	45	41.00	46.00	45.00	132

Chi-square value of 5.18, with 6 degrees of freedom.
(Not significantly different)

Table 11.--Chi-square test of the relative numbers of different type of organisms attacked in tank 2, Experiment I and check tank 3, Experiment II

(T = Tank)

Types of food	Observed		Expected		Total
	T_2	T_3	T_2	T_3	
Bay mussel	0	4	1.63	2.37	4
Manila clam	13	11	9.78	14.22	24
Olympia oyster	20	32	21.18	30.82	52
Pacific oyster	0	1	0.41	0.59	1
Total	33	48	33.00	48.00	81

Chi-square value of 4.69, with 3 degrees of freedom
(Not significantly different)

Table 12.--Chi-square test of the distribution between species of first attacks made in each of the four tanks in Experiment I

(T = Tank)

Types of food	Observed				Expected				Total
	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4	
Bay mussel	3	0	1	3	1.81	1.69	1.69	1.81	7
Manila clam	6	4	7	3	5.16	4.84	4.84	5.16	20
Olympia oyster	3	11	3	5	5.68	5.32	5.32	5.68	22
Pacific oyster	4	0	4	5	3.35	3.15	3.15	3.35	13
Total	16	15	15	16	16.00	15.00	15.00	16.00	62

Chi-square value of 18.41, with 9 degrees of freedom.
(Significantly different)

Table 13.--Chi-square test of the distribution between species of first attacks made in tanks 1, 3, and 4 of Experiment I

(T = Tank)

Types of food	Observed			Expected			Total
	T_1	T_3	T_4	T_1	T_3	T_4	
Bay mussel	3	1	3	2.38	2.24	2.38	7
Manila clam	6	7	3	5.45	5.10	5.45	16
Olympia oyster	3	3	5	3.74	3.52	3.74	11
Pacific oyster	4	4	5	4.43	4.14	4.43	13
Total	16	15	16	16.00	15.00	16.00	47

Chi-square value of 3.64, with 6 degrees of freedom.
(Not significantly different)

Table 14.--Chi-square test of the distribution between species of first attacks made in tank 2, Experiment I and check tank 3, Experiment II

(T = Tank)

Types of food	Observed		Expected		Total
	T_2	T_3	T_2	T_3	
Bay mussel	0	1	0.5	0.5	1
Manila clam	4	4	4.0	4.0	8
Olympia oyster	11	10	10.5	10.5	21
Pacific oyster	0	0	0.0	0.0	0
Total	15	15	15.0	15.0	30

Chi-square value of 1.04, with 3 degrees of freedom.
(Not significantly different)

Table 15.--Chi-square test of the relative numbers of different types of organisms attacked in tanks 1 and 4 of Experiment II

(T = Tank)

Types of food	Observed		Expected		Total
	T_1	T_4	T_1	T_4	
Bay mussel	12	17	12.71	16.29	29
Manila clam	12	14	11.39	14.61	26
Olympia oyster	15	18	14.46	18.54	33
Pacific oyster	0	1	0.44	0.56	1
Total	39	50	39.00	50.00	89

Chi-square value of 0.96, with 3 degrees of freedom.
(Not significantly different)

Table 16.--Chi-square test of the distribution between species of first attacks in tanks 1 and 4 of Experiment II

(T = Tank)

Type of food	Observed		Expected		Total
	T_1	T_4	T_1	T_4	
Bay mussel	2	3	2.26	2.74	5
Manila clam	4	4	3.61	4.39	8
Olympia oyster	8	9	7.68	9.32	17
Pacific oyster	0	1	0.45	0.55	1
Total	14	17	14.00	17.00	31

Chi-square value of 0.96, with 3 degrees of freedom.
(Not significantly different)

Table 17.--Combined attacks in tanks 1 and 4 of Experiment II

Food animals	1st attack	2nd attack	3rd attack	4th attack	5th attack	6th attack	7th attack	8th attack	Total
Bay mussel	5	5	6	5	4	2	1	1	29
Manila clam	8	6	6	4	2	0	0	0	26
Olympia oyster	17	11	5	0	0	0	0	0	33
Pacific oyster	1	0	0	0	0	0	0	0	1
Total	31	22	17	9	6	2	1	1	89

Of the 17 drills that made first attacks on Olympia oysters (tables 6 and 8), 13 made two or more later attacks on food organisms. Six of these 13 drills later attacked Olympia oysters, while four made attacks on mussels and three on Manila clams when the Olympia oysters became scarce. The drills did not make subsequent attacks on Pacific oysters.

Of the eight drills that made first attacks on clams (tables 6 and 8), six made two or more attacks on bivalves. Three of these six drills made later attacks on clams, while three made attacks on bay mussels.

Of the five drills that first attacked mussels, three made two or more subsequent attacks on mussels, but none of the three changed species in later attacks.

Duration of Attacks

For the four tanks in Experiment I, significance of differences in the duration of drill attack on different species of bivalve (tables 2 through 5) were tested by analysis of variance (Snedecor, 1956). The sums of squares, mean squares, and "F" values of the analysis of variance tests are shown in table 18 (part A through D) for individual species of pelecypods. None of the four "F" values was significant at the 5 percent level.

When the appropriate data from check tank 3 of Experiment II (table 7) were included in the analysis of variance test of clams and Olympia oysters (table 18, part B and C), the "F" values were still not significant at the 5 percent level. Insufficient data from the check tank 3 prevented further check on the bay mussel and Pacific oyster observations of Experiment I.

A one-way analysis of variance was also calculated for the duration of drill attack in days, between the four species of bivalves of Experiment I. The "F" value was significant as shown in table 18, part E.

Table 19 contains the combined data from Experiment I and shows the number of food organisms attacked by the drills and the duration of attacks. The average number of days taken by the drills in Experiment I to bore through

Table 18.--"F" values from analysis of variance tests between the four tanks of Experiment I on days required to drill and finish feeding on the four species of bivalves

BG : Between groups

WG : Within groups

	Bivalves	Sums of squares BG : WG	Degrees of freedom BG : WG	Mean squares BG / WG	"F" values (5% level)
A.	Bay mussels (no mussels were attacked in Tank 2)	3.77 : 45.79	2 : 33	1.89 / 1.39	1.36 (not significant)
B.	Manila clams 1/	40.25 : 305.69	3 : 59	13.42 / 5.18	2.59 (not significant)
C.	Olympia oysters 2/	19.16 : 409.51	3 : 44	6.39 / 9.31	0.69 (not significant)
D.	Pacific oysters (no Pacific oysters were attacked in Tank 2)	14.98 : 54.13	2 : 15	7.49 / 3.61	2.07 (not significant)
E.	Between the 4 species	254.62 : 893.28	3 : 161	84.87 / 5.55	15.29 (significant)

1/ If the clam data from check tank 3, Experiment II were included in this analysis, "F" = 11.70/5.34 = 2.19 (not significant at the 5% level, with 4, 69 degrees of freedom)

2/ If the Olympia oyster data from check tank 3, Experiment II were included in this analysis, "F" = 5.89/6.83 = 0.86 (not significant at the 5% level, with 4, 75 degrees of freedom)

a shell and consume the soft parts were as follows: clams, 7.3 days; Olympia oysters, 6.5; Pacific oysters, 5.1 days; and mussels, 4.1 days.

The average number of days taken by the drills in check tank 3, Experiment II, to drill through and consume the soft parts were as follows: clams, 8.1 days; Olympia oysters, 6.2 days; Pacific oysters, 6.0 days; and mussels, 4.8 days (table 20).

The average number of days for drills from tanks 1 and 4 (combined) of Experiment II to penetrate the shells and consume soft parts were as follows: clams, 7.4 days; Olympia oysters, 6.0 days; Pacific oysters, 5.0 days; and mussels, 4.8 days (table 20).

Effect of Thickness of Prey's Shell

Table 21 summarizes the correlation and regression analyses between the duration of attack in days and the corresponding thickness of the perforated shells expressed in ten-thousandths of an inch. No correlation could be demonstrated for the clams; but the data of mussels, Olympia oysters, and Pacific oysters showed positive correlation between days (Y) and thickness (X). Also, the "t" tests of hypothesis (slope) $\beta = 0$ were significant for all three species. The regression lines for the three species are shown in figure 5, and the regression equations are as follows:

Bay mussels: $\hat{Y} = 4.1389 + 85.6989\ (X_0 - .0220)$

Olympia oysters: $\hat{Y} = 6.5625 + 123.7722\ (X_0 - .0418)$

Pacific oysters: $\hat{Y} = 5.3529 + 103.6502\ (X_0 - .0316)$

Table 19.--Number of organisms attacked and duration of attack for Experiment I

A : number of organisms attacked
B : duration of attack in days
C : average duration

	1st attack A-B-C	2nd attack A-B-C	3rd attack A-B-C	4th attack A-B-C	5th attack A-B-C	6th attack A-B-C	7th attack A-B-C	Total attack A-B-C
Manila clam (C)	20-164-8.2	22-145-6.6	15-111-7.4	4-23-5.8	2-14-7.0	0	0	63-457-7.3
Olympia oyster (O)	22-157-7.1	15- 92-6.1	7- 44-6.3	3-14-4.7	1- 4- 4.0	0	0	48-311-6.5
Pacific oyster (P)	13- 70-5.4	3- 12-4.0	1- 3-3.0	1- 7-7.0	0	0	0	18- 92-5.1
Bay mussel (M)	7- 34-4.9	7- 30-4.3	7- 31-4.4	4-12-3.0	5-19-3.8	5-19-3.8	1-4-4.0	36-149-4.1

Total number of attacks = 165

Table 20.--Duration of attack on each species of food animal

	All tanks Experiment I	Tank No. 3 Experiment II	Tanks No. 1 and 4 Experiment II	General indication
Manila clams	7.3 days	8.1 days	7.4 days	7-8 days
Olympia oysters	6.5 days	6.2 days	6.0 days	6-7 days
Pacific oysters	5.1 days	6.0 days	5.0 days	5-6 days
Bay mussels	4.1 days	4.8 days	4.8 days	4-5 days

Table 21.--Summary of correlation and regression analyses between the duration of attack in days, and the corresponding thickness of perforated shells 1/

	N	ΣY	ΣX	ΣY^2	ΣX^2	ΣXY	$S_{y/x}$	b	"r"	"t"
Manila clam (C)	59	429	3.2322	3,449	.18539	23.9134	2.3292	49.5783	.248 @	---
Olympia oyster (O)	48	315	2.0061	2,487	.09959	15.1206	1.9658	123.7722	.755	9.95 *
Pacific oyster (P)	17	91	.5372	551	.01959	3.1482	1.5411	103.6502	.793	3.45 *
Bay mussel (M)	36	149	.7927	665	.01838	3.3606	1.1045	85.6989	.376	2.37 *

1/ N: number
Σ: summation
Y: duration of attack in days
X: thickness of drilled shells in inches
$S_{y/x}$: sample standard deviation of Y on X
b: estimated slope
"r": correlation coefficient
"t": value of "t" test on the slope
@: not significant at the 5 percent level
*: significant

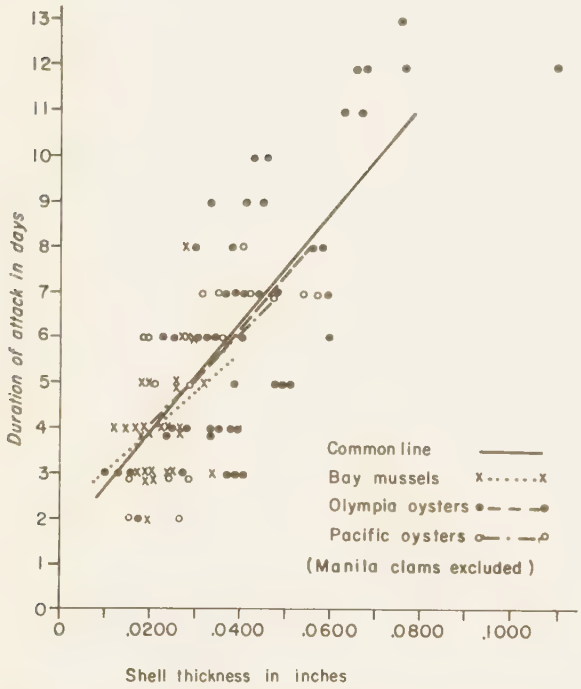

Figure 5.--Regression lines and scatter diagrams of duration of attack upon thickness of shells from Experiment I.

The mussel, Olympia oyster, and Pacific oyster data may be represented by one common line (fig. 5) as shown by an analysis of covariance test (table 22).

To determine the duration of attack (Y) for a given thickness of shell (X), all available data from Experiment I were combined and analyzed. The "r" value for these data was 0.696 (158 degrees of freedom), which indicates that there was a positive correlation between Y and X. Also a significant "t" value of 12.23 (testing hypothesis $\beta = 0$) was obtained. A regression line was therefore fitted to the plotted data in figure 6 to show this relationship. The $\hat{Y}$ estimate for the regression line in figure 6 was $\hat{Y} = 6.1500 + 96.4120 (X_O - .0411)$. The 95 percent confidence intervals for the regression line and individual points were also plotted in this figure.

DISCUSSION

From the results of this study, it was difficult to state specifically which species of food animal was preferred by *Ocinebra*. Throughout this study, *Ocinebra* generally preferred Manila clams, Olympia oysters, or bay mussels to Pacific oysters.

In Experiment I, the drills showed a general preference for Manila clams, followed closely by bay mussels and Olympia oysters. In Experiment II the Olympia oysters were attacked in preference to bay mussels and Manila clams. Chew and Eisler (1958) indicated that *Ocinebra japonica* preferred bay mussels and Manila clams to either Pacific or Olympia oysters.

Table 22.--Analysis of covariance test on the data (duration of attack and thickness of prey's shell) for bay mussel, Olympia oyster and Pacific oyster 1/

Source	Sums of Squares	Degrees of Freedom	Mean Squares
Total	175.88	99	---
Within groups (error)	174.87	95	1.8407
Between groups	1.01	4	.2525

"F"= $\frac{.2525}{1.8407}$ = .137 (not significant at the 5% level - therefore, one common line can represent the data)

1/ The technique employed here was to test first for a common line for the data. If such a common line is found, it is then unnecessary to test further for common slopes or common means as a common line implies that any differences in slopes or means are insignificant.

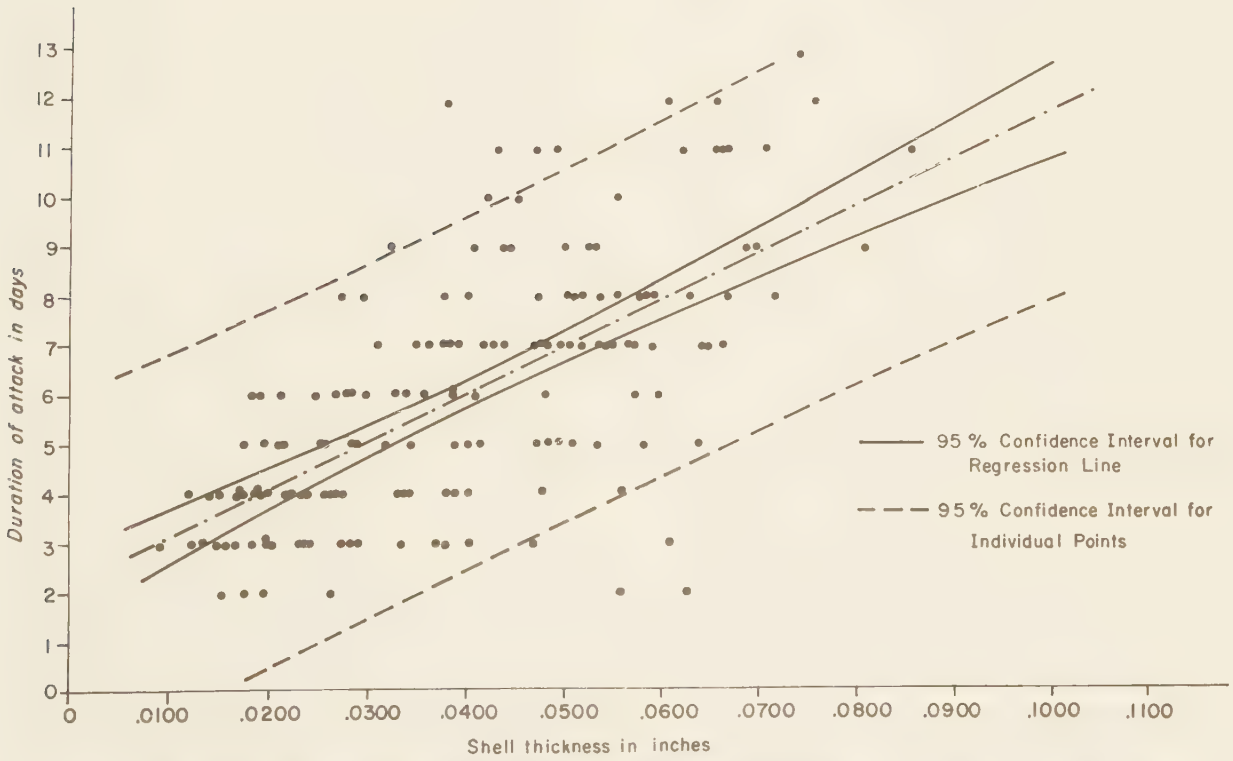

Figure 6.--Regression line and scatter diagram of duration of attack upon thickness of all shells from Experiment I.

In all cases, the Pacific oysters were the least preferred.

Tanks which differed in the numbers of various species attacked, also differed in the distribution of first attacks.

In Experiment I there were 103 possible chances (total possible pairs of attacks, tables 2 through 5) for a drill to attack the same species that it had attacked previously. Of these, 84 pairs were attacks of the same species. This, as well as the tank 2 test, suggested that a drill might continue to attack the same species of food organism that it had attacked previously, rather than move to an organism of a different species. If this hypothesis is accepted, it might be expected that the number of attacks would be greatest upon Pacific oysters, since the drills were taken from this species of Mollusk originally. This was not the case as noted above. It should be mentioned that when the drills were collected off of *Crassostrea gigas*, many drills were depositing egg cases. Thus, it does not necessarily mean the drills were attacking Pacific oysters when collected. According to Chew and Eisler (1958), some *Ocinebra* deposited egg cases in the early days of an experiment. These egg cases were cemented on the shells of several Pacific oysters and on the bottoms and sides of two experimental aquaria. They noted that no egg cases were found on any other test animal including Olympia oysters, bay mussels, and Manila clams, indicating that the Japanese drill may be able to differentiate between species of bivalves. Possibly this could have occurred in the field, when the drills were collected for this study.

Positive correlations existed between the thickness of prey's shells and the duration of attack on bay mussels, Olympia oysters, and Pacific oysters. No correlation was found between duration of attack and thickness of clam shells. The narrow range in shell thickness might have accounted for this lack of correlation. *Ocinebra* took the least number of days to drill and eat the bay mussels (4-5 days), followed in increasing order by the Pacific oysters (5-6 days), Olympia oysters (6-7 days), and Manila clams (7-8 days). The mean shell thickness of the four food species used in Experiment I fell in this same order (bay mussels, 0.0220 inch; Pacific oysters, 0.0316 inch; Olympia oysters, 0.0418 inch; and Manila clams, 0.0548 inch). Therefore, it is probable that the variations in duration of attacks were the result of differences in thickness of bivalve shells.

When daily observations were made, one or two drills were usually found on the walls of the tanks. Some ascended the wall to the surface of the water. When they descended to the edge of the floor of the tank, they were not confronted with an equal choice of the four species of food. However, a drill usually moved down the wall and temporarily on to an animal at the periphery of the group of food species, then moved within the group before making an attack. It is believed that the error due to this factor is not great enough to affect the results of these experiments.

An *Ocinebra* frequently drilled halfway through the valve of a victim and then stopped to move to another prey. Another drill sometimes moved onto the first prey and continued drilling on the vacated hole. The second drill usually finished the hole started by the first. For example, as noted in the daily record, drill number 12 (tank 3, Experiment I) attacked and drilled halfway through the shell of a clam (location L5) from August 13 to 17. After this drill moved off the bivalve (August 17), another drill moved onto this same clam on August 20 and continued drilling in the same hole.

It was not uncommon to observe two or three drills attacking the same victim, but only two cases (both Manila clams) were observed where two complete perforations were found on the same food animal. In other cases, one completely perforated hole and one or two half-drilled holes were found. Federighi (1931) and Galtsoff et al. (1937) also have reported that two or more *Urosalpinx cinerea* may attack an oyster simultaneously.

No study has been made on the feeding processes of *Ocinebra*; however,

because of the close systematic relation of *Ocinebra* to *Urosalpinx*, it is probable that their feeding processes are similar. According to Carriker (1955), *Urosalpinx cinerea* has a feeding process which consists of a mechanical rasping of the softer flesh of the prey. The proboscis is extended through the newly drilled hole and the radula tears away bits of flesh with its sharp, backward-pointed teeth. Flesh caught on the radular teeth and transported into the buccal cavity is neatly removed by esophageal suction and then carried by ciliary peristaltic activity to the stomach.

The precise mechanism by which the Japanese drill differentiates between species of prey is unknown. Sizer (unpublished report)[2], Galtsoff et al. (1937), and Federighi (1931) pointed out that *Urosalpinx cinerea* possessed an osphradium--an organ intimately connected with the gills and generally placed near their base. *Urosalpinx* may possibly be attracted to the food through the osphradium. Whether or not this applies to *Ocinebra* is unknown.

Water samples were taken when the test animals were collected in the field in order to observe changes in pH and salinities to which the drills were subjected in being transferred from the field to the aquarium. The differences were greatest when the drills were brought in for Experiment I. No literature has been published on the pH tolerance level of *Ocinebra*. As for salinities, Chapman and Banner (1949) claim 22‰ and above had little effect on *Ocinebra japonica*, while salinities below 12‰ were lethal.

The average pH of the water throughout this study was 7.32 (ranging from 7.00 to 7.52). Normally, the hydrogen ion concentration of the water within the recirculating system increases over a period of time, depending on the number and kinds of animals held in the aquarium.

When the pH approached 7.00, most of the old water in the system was drained out through the sewer, and new water was pumped in from a reserve supply. New water was introduced twice during this study (August 20 and November 12, 1957).

The average salinity in the aquaria throughout this study was 29.47‰ (ranging from 29.19 to 30.03). The salinity of the aquarium sea water was found to decrease with time. It was expected to increase, since a certain amount of water evaporation should have been expected. The decrease in salinity is probably due to condensation of moisture from the warmer air on the colder exposed surfaces of the tank where it can drop into the system.

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SUMMARY

1. To obtain a group of test animals that were from the same environmental surroundings, all test animals were collected in a single locality within a radius of 150 yards.

[2] Unpublished report by I. W. Sizer, 1936. Observations on the oyster drill with special reference to its movement and to the permeability of its egg case membrane. U. S. Bureau Fisheries, Washington, D. C.

2. Test animals collected in the field were measured for length. After the measurement, a size range for each species was selected around the mean to represent the sizes of drills and bivalves most abundant in the area of collection.

3. Two experiments, each of 70 days duration, were conducted in which individually marked *Ocinebra japonica* were presented with a choice of four different food organisms: bay mussels, *Mytilus edulis*; Manila clams, *Venerupis japonica*; Pacific oysters, *Crassostrea gigas*; and Olympia oysters, *Ostrea lurida*.

4. Drills generally preferred Manila clams, Olympia oysters, or bay mussels to Pacific oysters.

5. Tanks, which differed in the number of various species drilled and eaten, were also found different in the distribution of first attacks.

6. Results showed that a drill usually continues to attack the same species of food organism that it had attacked previously and does not tend to move to another organism of a different species.

7. The duration of drill attacks on an individual species of food animal was the same for the tanks that were compared. The duration of drill attacks between species were significantly different.

8. The results indicated that, on the average, the drills took 7 to 8 days to drill and finish feeding on Manila clams, 6 to 7 days for Olympia oysters, 5 to 6 days for Pacific oysters, and 4 to 5 days for bay mussels.

9. Variations in duration of attacks were probably the result of the differences in thickness of bivalve shells rather than in the time required to consume the edible parts.

10. An *Ocinebra* frequently drilled halfway through a prey's shell, and then moved to another prey. Another drill sometimes moved onto the first prey and usually continued drilling in the same hole.

11. It was not uncommon to observe two or three Japanese drills attacking a single bivalve.

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